"PERMANENT DEFORMATION CHARACTERIZATION OF BITUMINOUS MIXTURES: LABORATORIAL TESTS"

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ABSTRACT: In the last years some laboratorial tests are used to predict the permanent deformation behaviour of bituminous mixtures. Among those tests the Wheel Tracking test, the Cyclic Compression Test (Uniaxial and Triaxial) and the Repetitive Shear at Constant Height (RSCH) test, are considered for Portuguese practice. Also come out recently new European standards for those tests, with exception of the RSCH which is essentially used in the USA. Nevertheless some of testing conditions are not very well defined. Therefore, it is important to study the reliability and accuracy of each test in the task of predicting permanent deformation behaviour. In this work these test were used in the evaluation of a commonly used mixture in Portugal. Results show that all tests are suitable for predicting permanent deformation behaviour. Thus simpler and cheaper tests are more interesting to use.

KEY WORDS: Permanent deformation, bituminous mixtures, laboratorial tests

1. INTRODUCTION

The permanent deformation of bituminous mixtures is a common cause of distress. However a simple and effective methodology to evaluate behaviour to permanent deformation is not available in current practice. In Portugal the summer high temperatures and the growing heavy vehicle traffic are motives of concern. It is expected that failures in road pavements due to permanent deformation in bituminous mixtures will increase. It is therefore of great importance to evaluate the permanent deformation behaviour in a simple but accurate way [1].

In the last years some laboratorial test like the Wheel-Tracking, the Uniaxial Cyclic Compression, Triaxial test and the Repeated Shear at Constant Height have been used to study this matter [2]. Recently the European standards for these tests are available, except for the Repeated Shear at Constant Height which is used mainly in the USA.

The use of these tests in current practice is of great interest but some questions remain to be solved. The procedures are in some tests not totally defined and the limits to the test results are far from being well-known. It is not easy to solve these questions in particular because there will probably be variations from country to country according to the local conditions and practice.

One other issue of concern is that these four tests are intended to achieve the same goal. In the Portuguese practice the existence of several types of permanent deformation characterisation tests has no interest. It became necessary to select the one that gives the best results for local conditions.

Therefore, the propose of this work was to study the reliability for the Portuguese conditions of the mentioned permanent deformation tests, how well they could perform and which of them is suitable to be the elected to do the job.

2. LABORATORIAL WORK

A typical bituminous mixture was used in this study [3]. This mixture is commonly used in base layers and also in binder layers. The Portuguese practice indicates that this is a rather stiff mixture.

The mixture was made using a lime stone aggregate. The aggregate gradation curve is shown in Figure 1.

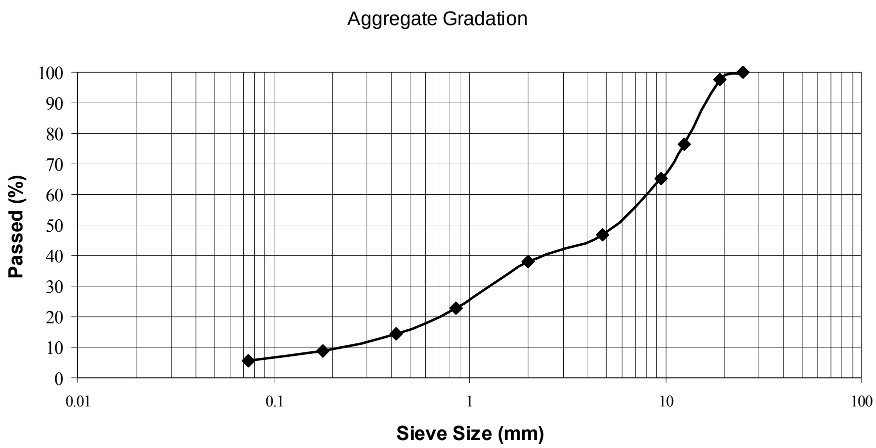


Figure 1. Aggregate Gradation curve

Three different series of specimens were made using three different percentages of bitumen in order to have different behaviours to permanent deformation. The percentages of bitumen used were 3.7%, 4.2% and 4.7%. These percentages are in the range used in the Portuguese practice. For each test, laboratory specimens and cored specimens in a road pavement were used.

2.1 Wheel-Tracking Tests

This test followed the prEN 12697-22 [4]. It was used a small size device model A, with the temperature conditioning of the specimen made in an air. The samples were compacted with a small drum roller.

Each test takes 45 min with 21 load cycles per minute. The test temperature used was 45 ºC. This value was chosen because it is representative, for Portuguese conditions, of the service temperatures at a pavement depth of 10 cm [6].

At the temperature of 45 ºC, the mixture had a flexural resistance that permits the evaluation of the tests sensibility with a realistic behaviour, which is not the case if the chosen test temperature was 60º C, for instance.

Six laboratory and nine in situ cored specimens were tested. Each specimen dimensions was 305*305*80 mm^3.

In Figure 2 and in Table 1 the results of the Wheel-Tracking test are presented. Typically one has a deformation curve showing the axial deformation (mm) versus time (s). On the linear part of the curve the deformation rate (TRm) [4] was determined, from minute 30 to minute 45. The average axial deformation in the test (d_{45}) is also shown.

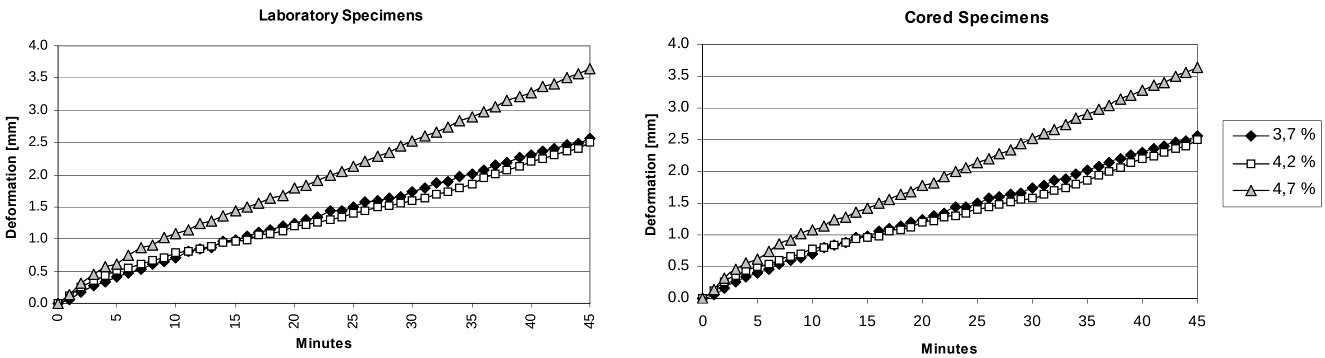


Figure 2. Wheel Tracking curves

Table 1. Wheel Tracking results

Pb [%]	Origin	Bulk Specific Gravity [g/cm3]	d_{45} [mm]	TRm [mm/h]
3,7	Laboratory	2.40	2,30	1,18
4,2	Laboratory	2.37	3,19	2,07
4,7	Laboratory	2.38	2,49	2,25
3,7	Cored	2.35	2,91	3,32
4,2	Cored	2.39	3,70	3,67
4,7	Cored	2.40	4,80	4,32

In Figure 3 it is shown the relation between the percentage in bitumen and the deformation ratio (TRm) obtained in the test. The correlation factors are very high. The results indicate that higher percentages of bitumen lead to higher deformation rates for both, laboratory and pavement cored specimens. This is a normal result regarding permanent deformation behaviour.

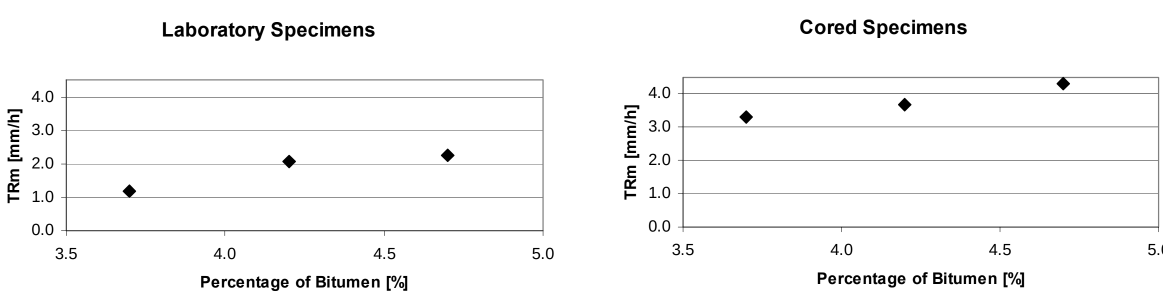


Figure 3. Relation between the TRm and the percentage in bitumen for laboratory and cored samples

2.2 Uniaxial Cyclic Compression Test

For this test the standard prEN 12697-25 [5] was followed. The Uniaxial Cyclic Compression test is performed in specimens with 150 mm diameter and 100 mm height. The prEN 12697-25 indicates that the upper load plate should have only 96 mm of diameter. For this test, as for the others, laboratory made and in situ cored specimens were tested. The laboratory specimens were compacted using a vibratory plate.

The applied load had a haversine shape with 1sec of loading time and 1sec of rest time. The test duration is 3600 cycles and the test temperature was 45 ºC. The maximum axial stress was 150 kPa. In the Figure 4 the shape of the load is shown.

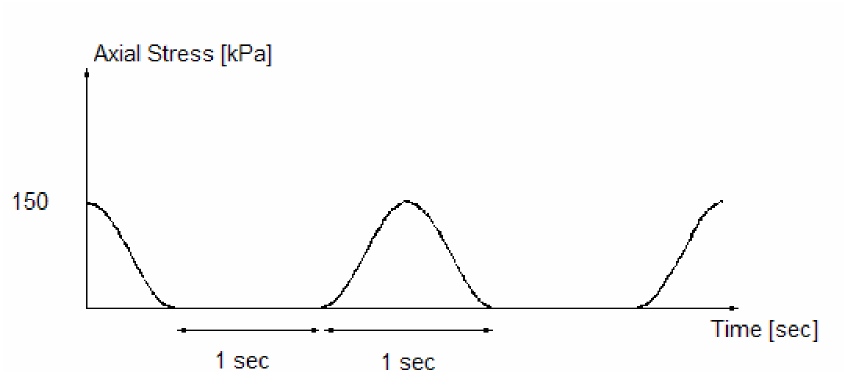


Figure 4. Uniaxial Cyclic Compression Test loading

The result of this test is a deformation curve similar to the one presented in Figure 5 [6]. After a conditioning stage (phase 1), which simulates the pos-compaction that takes place on the field after placing the bituminous layer, the specimen is expected to be in "phase 2" (linear phase) of the evolution of permanent deformation. From this "phase 2" it's possible to determine the Creep Rate (permanent strain over the number of cycles). In this work the Creep Rate was determined from cycle 2000 to cycle 3600.

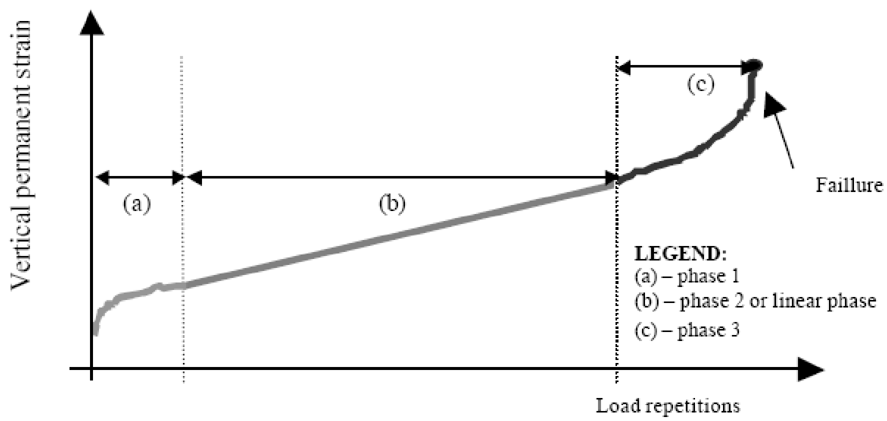
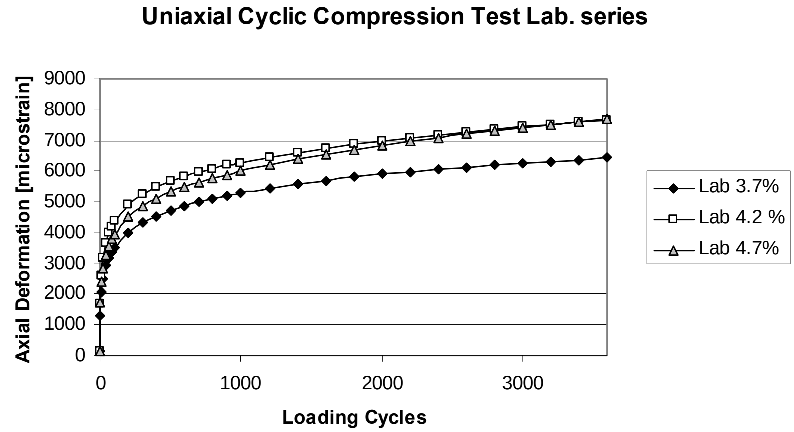


Figure 5. Evolution of the deformation of bituminous mixtures

In Table 2 and in Figure 6 the results obtained are shown. The higher the bitumen percentage the higher the Creep Rates obtained. In both the laboratory specimens and the in situ cored specimens a higher percentage in bitumen led to higher creep rates, confirming the results obtained with Wheel Tracking, as expected.

Table 2. Results from the Uniaxial Cyclic Compression Test.

Pb [%]	Origin	Bulk Specific Gravity [g/cm^3]	Average Deformation [mm]	Creep Rate [μstrain/cycle]
3.7	Lab.	2.378	0.643	0.339
4.2	Lab.	2.424	0.710	0.400
4.7	Lab.	2.405	0.725	0.515
3.7	Cored	2.376	0.988	0.728
4.2	Cored	2.407	1.124	0.965
4.7	Cored	2.408	1.440	1.650



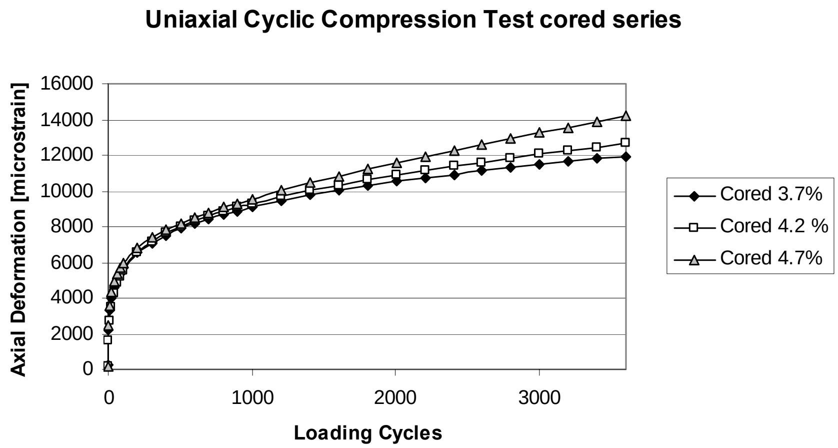


Figure 6. Relation between the Bitumen content and the deformation rate in the Uniaxial Cyclic Compression Test

Comparing the evolution of Creep Rate with percentage of bitumen (Figure 7) it can be said that it is of the same type but with higher values for cored specimens (as for the total axial deformation, Table 2). The reasons for this should be related with the compaction characteristics for both types of specimens.

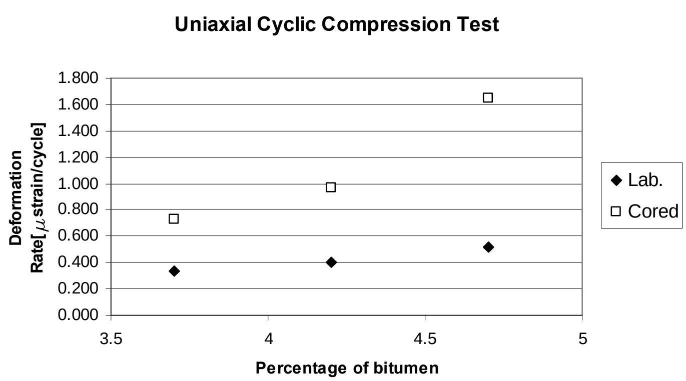


Figure 7. Relation between the Creep Rate and the bitumen content

2.3 Repeated Shear at Constant Height

The Repeated Shear at Constant Height (RSCH) test followed procedure AASHTO TP7 [7]. The test is performed in specimens with 150 mm diameter and 50 mm height. Laboratory specimens were cored from a slab made in laboratory and compacted with a small drum roller. Six specimens were made in laboratory and six specimens were cored from a road pavement.

The test was performed at 45 ºC. Conditioning to test temperature is made in air for 2 hours. The load had a haversine shape corresponding to a 70 kPa shear stress magnitude with a 0.1 sec loading time and 0.6 sec rest period. The tests had 5000l loading cycles. Six laboratory made and six in situ cored specimens were tested. The results are presented in Table 3. The Dynamic Shear Modulus and the Permanent Strain at 5000 Cycles were the parameters chosen to characterize the mixture behaviour.

Table 3. Results from the RSCH test

Origin	Pb [%]	Bulk Specific Gravity [g/cm^3]	Shear Modulus [MPa]	Perm. Shear Strain 5000 Cycles
Lab.	3.7	2.393	144.4	0.0396
Lab.	4.2	2.400	195.1	0.0363
Lab.	4.7	2.387	128.8	0.0532
Cored	3.7	2.398	319.9	0.0084
Cored	4.2	2.373	260.1	0.0165
Cored	4.7	2.383	176.6	0.0264

From these results it seems that the shear modulus and the permanent shear strain at 5000 cycles are able to access the behaviour of the mixture to permanent deformation. Both give the same classification of the mixtures as the other tests involved in this study.

The laboratory specimens with 3.7 percent of bitumen seem to perform worst than the specimens with 4.2 percent of bitumen. This could be because only two specimens were tested. For the in situ cored specimens the classification of the mixtures is the correct one. In Figure 8 are shown the results for the laboratory and cored specimens.

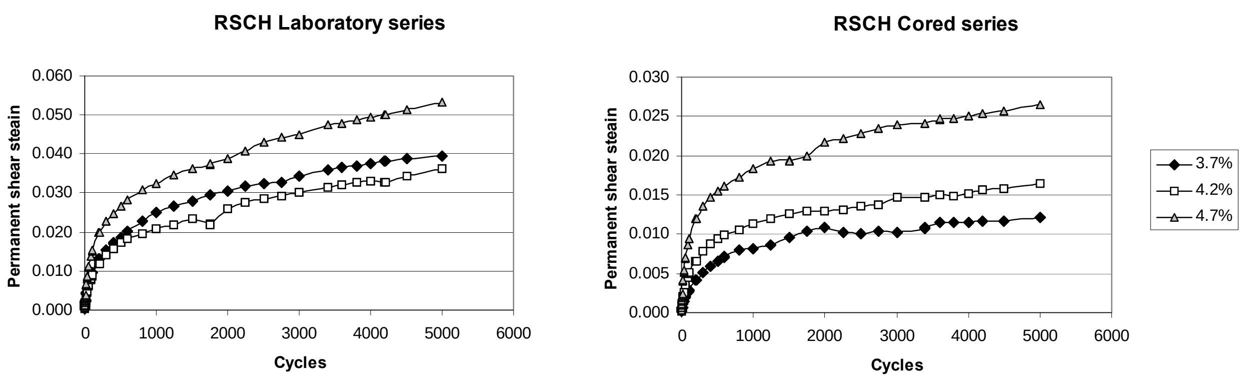


Figure 8. Results of the RSCH Test

In Figure 9 is shown the values of the dynamic shear modulus and the permanent strain at 5000 cycles versus the bitumen content. The values show that the mixtures with higher percentage in bitumen had worst performance. The cored specimens had better results than the laboratory made specimens. Both Dynamic Shear Modulus and Permanent Strain at 5000 cycles point at the same conclusions, with a very similar classification of mixtures.

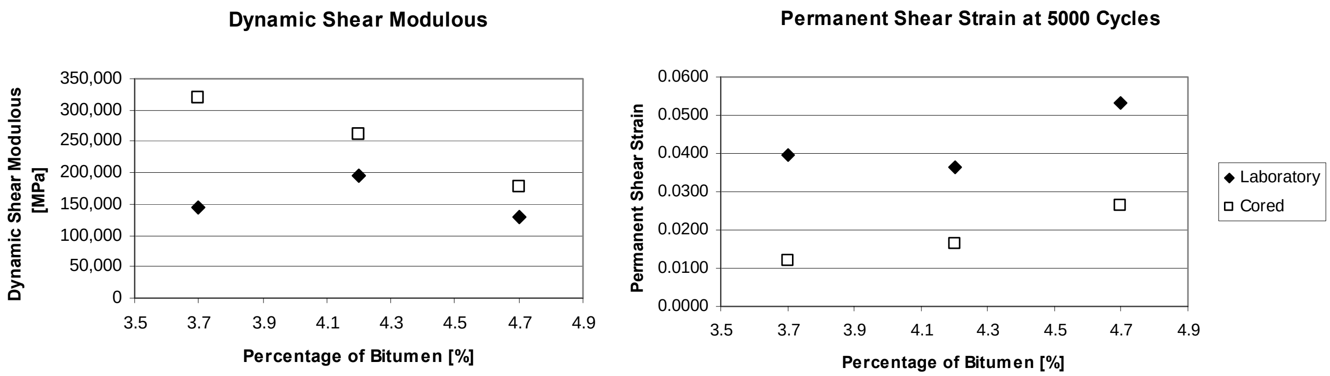


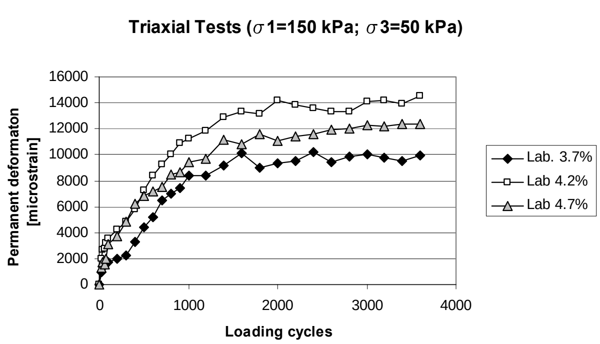
Figure 9. Values of the Dynamic Shear Modulus and permanent shear strain versus bitumen content

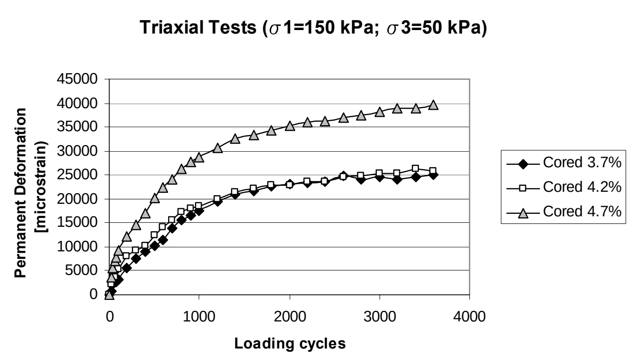
2.4 Triaxial Tests

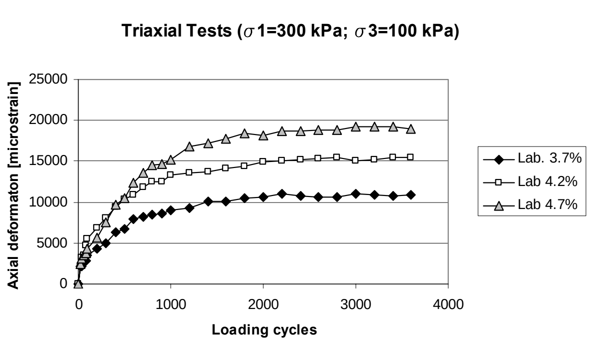
For this test the standard prEN 12697-25 [5] was followed. This test is performed in specimens with 150 mm diameter and 100 mm height, the cored specimens where shorter with 80 to 90 mm height. Because of the low height/diameter ratio a lubricant between the loading plates and the specimen was used.

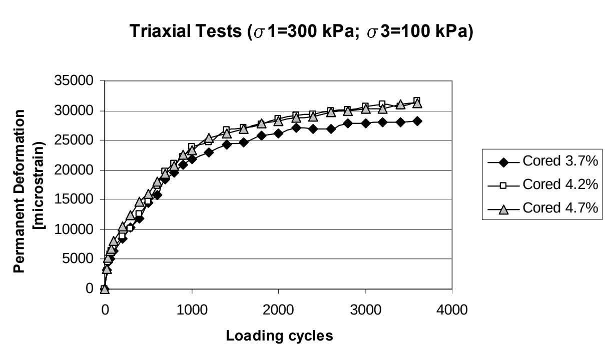
The applied load had a haversine shape with 1sec of loading time and 1sec of rest time. The test duration was 3600 cycles and the test temperature was 45 ºC. The triaxial tests were made with three different tension levels, σ_1=150 kPa and σ_c= kPa, σ_1=300 kPa and σ_c=100 kPa, σ_1=600 kPa and σ_c= 200kPa.

The results of this test are deformation curves similar to those obtained in the Uniaxial Cyclic Compression test. From the linear part of the curve it's possible to determine the Creep Rate [5]. In this work the Creep rate was determined between the cycle 2000 and the cycle 3600.









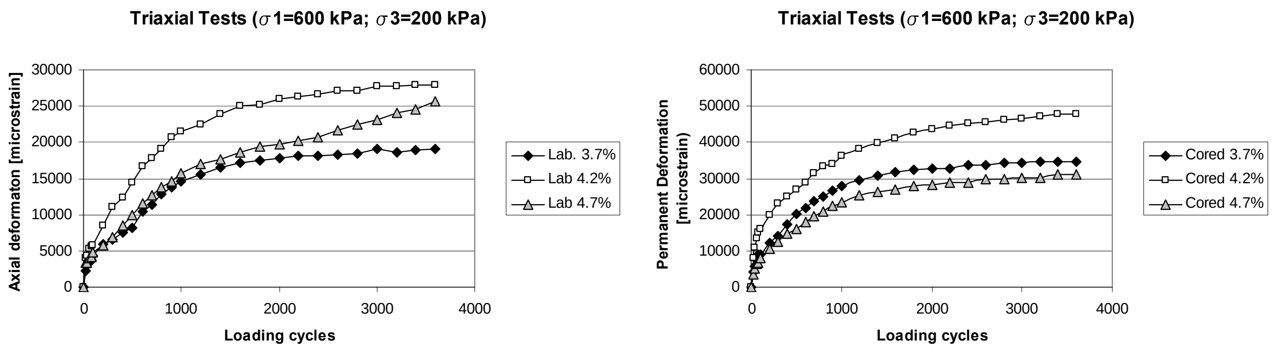


Figure 10. Triaxial Tests deformation curves

Table 4. Result from the Triaxial Tests.

Origin	Pb [%]	Bulk Specific Gravity [g/cm3]	σ1max [kPa]	σc [kPa]	Creep Rate [μstrain/cycle]
Lab.	3.7	2.409	150	50	0.333
Lab.	4.2	2.418	150	50	0.640
Lab.	4.7	2.435	150	50	0.852
Lab.	3.7	2.404	300	100	0.262
Lab.	4.2	2.414	300	100	0.374
Lab.	4.7	2.429	300	100	0.558
Lab.	3.7	2.413	600	200	0.858
Lab.	4.2	2.428	600	200	0.858
Lab.	4.7	2.420	600	200	3.576
Cored	3.7	2.375	150	50	1.241
Cored	4.2	2.365	150	50	1.729
Cored	4.7	2.417	150	50	2.738
Cored	3.7	2.399	300	100	1.131
Cored	4.2	2.383	300	100	1.939
Cored	4.7	2.398	300	100	1.859
Cored	3.7	2.364	600	200	1.357
Cored	4.2	2.369	600	200	1.200
Cored	4.7	2.395	600	200	2.765

The results show that specimens with higher bitumen content had higher Creep Rates. This is more evident in the laboratory specimens, the cored specimens had higher Creep Rates but the classification of the mixtures is more imprecise. The deformation rates also increased with the increase of the differential stress.

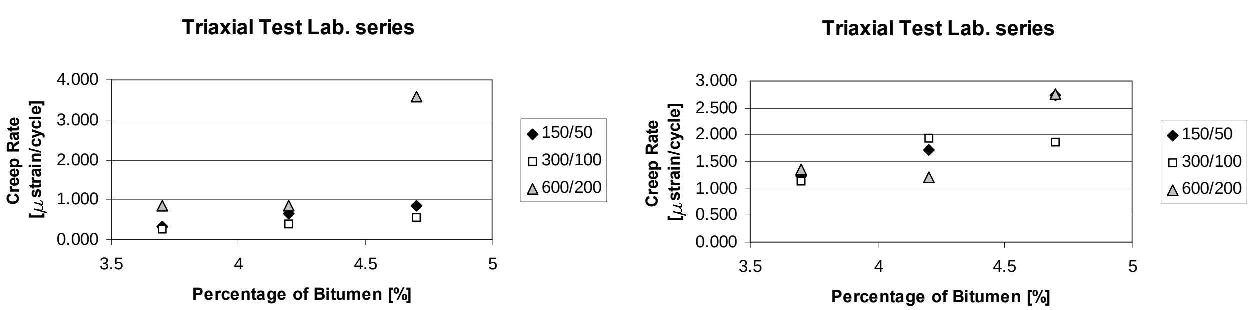


Figure 11. Creep Rate versus the bitumen content

3. RESULTS ANALYSIS

The analyses of the results show that the four tests are able to differentiate the behaviour of the three mixtures. If we consider the mixture type and the test conditions, we can say that the results show that these tests are very precise. In the following figures the results of the several tests are plotted. The correlation between the results of the Wheel Tracking tests with the results of the other tests is shown. For simplicity only the correlations with the Wheel Tracking tests are shown.

With a higher percentage of bitumen higher deformation rates are obtained. This is valid for the laboratory specimens and for the in situ specimens. Good correlations are obtained when the results of the different test are put side to side.

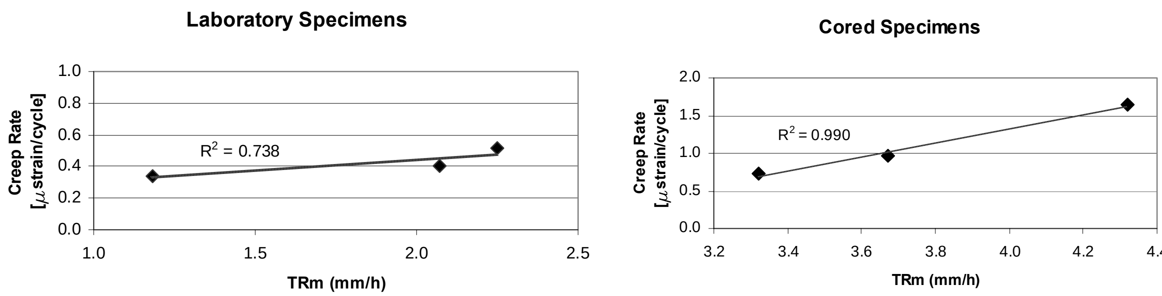


Figure 12. Relation between the Uniaxial Cyclic Compression Test and the Wheel Tracking Test.

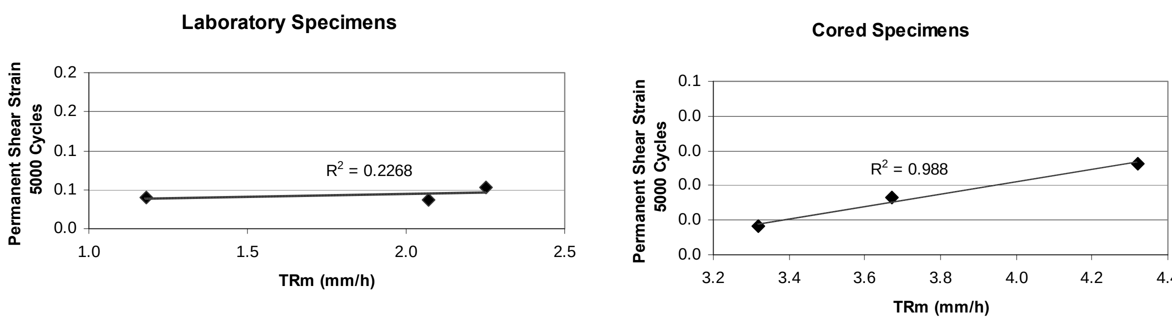


Figure 13. Relation between the RSCH Test and the Wheel Tracking Test.

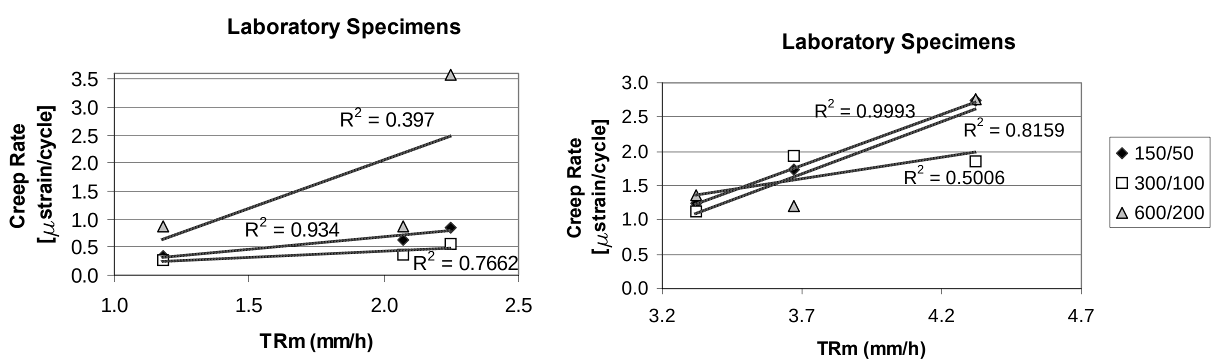


Figure 14. Relation between the 3D Test and the Wheel Tracking Test.

4. CONCLUSIONS

All tests give the same classification of the mixtures and allow to concluded that higher bitumen percentages correspond to higher deformation rates. This was true for the laboratory made and for the cored specimens.

Good correlations between the results of the different tests could be established. This means that they all characterize in the same way the behaviour of bituminous mixtures to permanent deformation.

Nevertheless, the use of tests like the Wheel tracking test or the Uniaxial Cyclic Compression test seems to be more interesting, as they are capable to characterize the behaviour of bituminous mixtures to permanent deformation and have simpler procedures and equipment. For the conditions used in this study the Wheel-Tracking Test and the Uniaxial Cyclic Compression test had better results in differentiating the mixtures and the classification was clearer.

The deformation rate obtained in the Wheel-Tracking Test and the creep rate obtained in the Uniaxial Cyclic Compression test are suitable values to characterize bituminous mixtures to permanent deformation.

The Laboratory specimens behave better in all tests except in the RSCH test. This could be explained by the manufacture process. But, more important than that is the fact that the rating of the mixtures is equal for the laboratory and cored specimens.

It can be concluded that all the tests can be used in the characterization of bituminous mixtures to permanent deformation. However, less complex and cheaper to run tests as the Wheel Tracking and Uniaxial Cyclic Compression tests seem to be more interesting for the practice.

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